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# HEALTH PHYSICS CONSIDERATIONS FOR HIGHLY RADIOACTIVE ENVIRONMENTS

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### SOME BASIC STUFF TO GET STARTED

- External radiation protection
  - Time, Distance, Shielding
    - \* 1/r<sup>2</sup> for distance
    - Shielding electron density for gammas, hydrogenous for neutrons (not an issue usually)
  - Sending the old guy
    - \* Teratogenic concerns
    - Cancer takes a while
    - \* But...younger folks may move faster and recover faster/be affected less
- \* Internal radiation protection
  - Keep it out of your body
    - Control it at the source
    - Minimize inhalation respirators, and time
    - \* Minimize ingestion PPE, hygiene, basic precautions
  - If it does get into you, we can minimize absorption, or increase excretion

#### MORE BASIC STUFF – UNITS

- \* Curies
  - \* 3.7 E10 DPS (3.7 E10 Bq)
  - Co-60 1.3 R/hr (11.34 mSv/hr) at 1m
  - Cs-137 321 mr/hr (2.82 mSv/hr) at 1m
  - \* Bqs
- \* Rem/Rad/Roentgen
- \* Regulatory vs practicable limits
  - \* 5 R (50 mSv) vs 25 R (250 mSv)
- ♦ Sv/Gy 100 R

# SCENARIO/ASSUMPTIONS

- \* Team is near a nuclear surface burst, well shielded from initial radiation
- \* Many of the statements include "it depends..." very few absolutes
- \* Radiation is only one part of the problems
- \* Adequate sealed food is available

#### NUCLEAR BLAST FUNDAMENTALS

- \* Yield is measured in kT
  - 1,000 tons of TNT-equivalent explosive force
  - \* Assuming 35 tons in semi-truck, 1kT = 28 semi trucks of TNT (>1/4 mile)
- Detonation is divided into 3 energy compartments\*
  - \* Shock 50%
  - ❖ Thermal 35%
  - \* Radiation 15%
    - Initial (within ~1min) 5%
    - Delayed (residual) 10% not counted in yield calcs

<sup>\*</sup>For a fission weapon w/HOB <40k feet. For thermonuclear weapons and other scenarios it changes.

## ELECTROMAGNETIC PULSE (EMP)

- \* All explosions can produce electromagnetic fields
- Nuclear explosions produce significant EMP because of prompt radiation
  - Prompt gamma radiation interact and ionize nearby molecules, charge separation creates electric field pulse
  - Ground is a good shield and conductor, and strong magnetic fields will be generated for a mile or more
- Damage occurs to electronics and electrical equipment
  - RF deposited in components
  - RF generates voltage surge especially on long conductors
  - Depends on duration of pulse, distance from deposition region, etc.
- \* Also Transient Radiation Effects (TREE) from direct radiation exposure
  - \* Ionization
  - Direct damage to materials

#### PROMPT RADIATION

Gammas 500 yd, 2 kt, 10kR (100Sv)

- From fissions
- From fission fragments
- \* From neutron activation
- \* Shielded by dense material

Neutrons 500 yd, 2 kt, 12kR (120 SV)

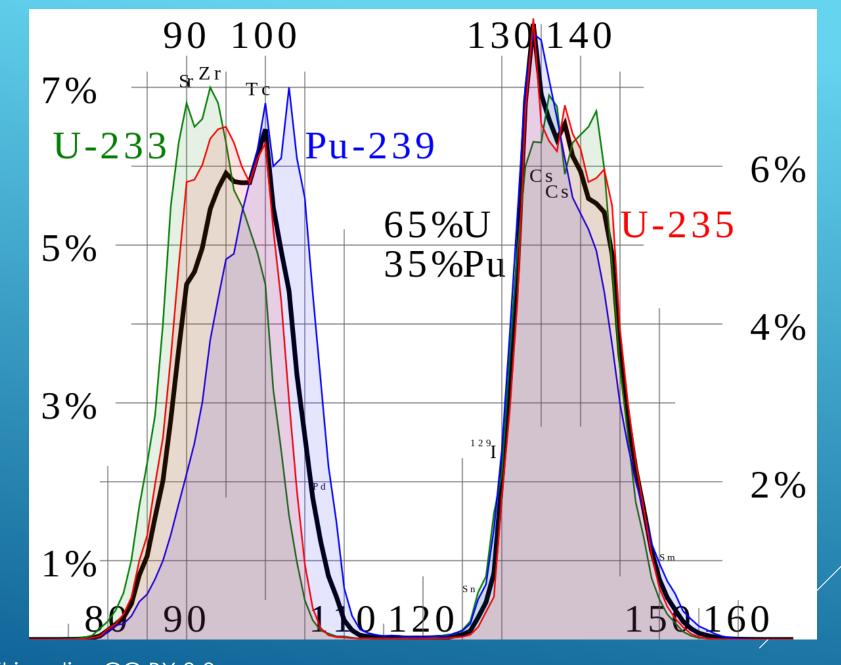
- \* From fission
- \* Moderated by hydrogenous material

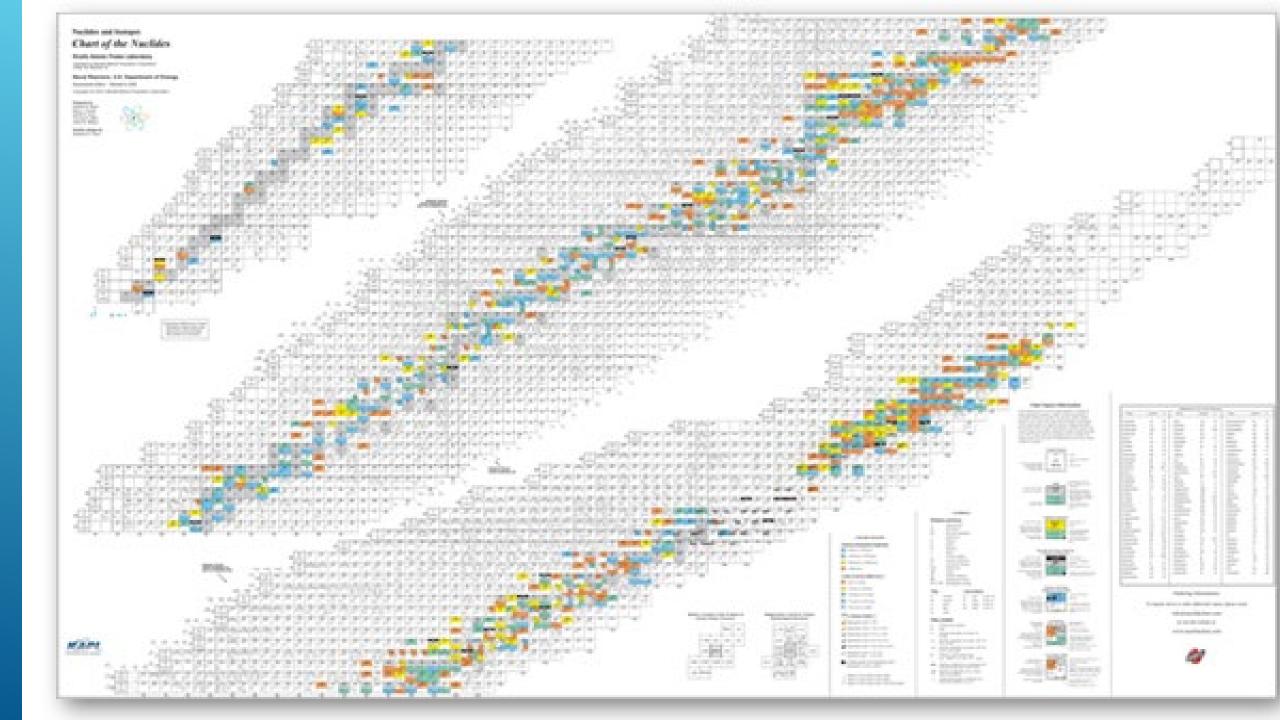
#### RESIDUAL RADIATION

- Fallout materials that were not lofted
  - Large particles resistant to resuspension or transport
  - Fission products
  - Activation of weapon, immediate surroundings
- Activation of materials in the vicinity of the burst by fission neutrons
- \* 3E23 fission product atoms/kt
- \* At 1 min 3E10 Ci (1.11 E21 Bq)
- \* 7/10 ROT For every factor of 7 in time, dose rate decreases by 1/10
  - Surface roughness
  - \* Fractionation and speciation

#### ISOTOPES IN FALLOUT

- ♦ 1 kt =~ 3E23 fission product atoms
- ♦ 10 tons = ~ 3 E21 fission fragments
- \* At 1 minute ~ 3 E8 Ci (1.11E19 Bq) does not account for activation products
- \* Many beta emitters, at 24 hrs a 2,000x reduction from 1 min value
- More than 300 isotopes identified, but about 80 are formed
- \* 1131 2% of FFs 1.6 E5 Ci (5.9 E15 Bq)/kt 10t = 1.6E3 Ci (5.9 E13 Bq)
- Sr90 & Sr89 3% of FFs 190 Ci (7E12 Bq)/kt and 3.8E4 Ci (1.4E15 Bq)/kt 10t = 2Ci (7.4 E10 Bq)
   & 380 Ci (1.4E13 Bq)
- $\star$  Cs137 ~3.25% of FFs 200 Ci/kt 10t = 2 Ci (7.4 E10 Bq)
- Other isotopes various physical and chemical states
  - \* Right place, right time, right size, right chemical form to have desired effect
  - \* Oxides, metals, gases, etc





7	E 3.0	567.2,··· E 4.71	E 2.0	E 3.71	E 1.20	E 2.9	E .60	E- 1.04 137,907107	138.906348	∂ <sub>γ</sub> 2.7, 69 E 3.762	E 2.502	E 4.50	E 3.43	E 5.5	E 4.1	E 6,7
		Ba131 1/+	Ba132	1/-Ba133 1/+ 1.621 d   10.53 a	Ba134	11/- Ba135 3/+	7- Ba136	11/-Ba137 3/+	Ba138	Ba139 7/-	Ba140 12.75 d	Ba141 3/-	Ba142	Ba143 5/-	Ba144	Ba
R* R*	E21 a	79.0, ε e β*νω β*	0.101 1E21 a	T 275.9 γ 12.3, γ 356.0,	2.417	1.20 d 6.592 1T 268.2	y 1048.1,	2.552 m IT 661.7	71.698	β-2.27, 2.14, γ 165.9,	β-1.0, .48, 1.02,··· γ 537.26, 29.97,···	β <sup>-</sup> 2.59, 2.73,··· γ 190.3, 304.2, 276.9, 343.7,···	β-1.0, 1.10,··· γ 255.3, 1204.1, 895.0, 231.6,···	β-3.24,··· γ 211.5, 798.8, 980.5,···	β-2.4, 2.9, γ 103.9, 430.5, 172.8, 156.6,	β-4.9, γ 97.1, §
	0+8), 5+20Ε1)	108.4 y 496.3, 123.8.	(.8+1E1), (4.7+2E1)	e <sup>-</sup> ε(ω) γ 632(ω) 81.0, 302.9, σ <sub>γ</sub> 4, 8Ε1	$\hat{\sigma}_{\gamma}$ (.1 + 1.4), 2E1	$\hat{\sigma}_{\gamma}$ (.014 + 6), (.5 + 1.3E2)	$\widehat{\sigma}_{y}$ (.010 + .4), (.1 + 1.5)	σ̂ <sub>γ</sub> 5.1, 4	∂ <sub>γ</sub> .43, .3	∂ <sub>y</sub> 5	â, 1.6, 14					
	9.90631 (\$129 1/+ 5	E 1.37	131.905056 Cs131 5/+	Cs132 2+	133.904503 Cs133 7/+	134.905683	135.904570 19/-Cs135 7/+	136.905821 8- Cs136 5+	137.905241 Cs137 7/+	6- Cs138 3-	E 1.05 Cs139 7/+	E 3.21 Cs140 1	Cs141 7/+	E 4.25 Cs142 0-	E 3.1 Cs143 3/+	Cs
	1.336 d	3.5 m 29.21 m 82.9, ε, β*	9.69 d	6.48 d	100	8- Cs1 34 4+ 2.90 h IT 127.5, β658,	53 m 2.3E6 a IT 846.1 β21	19 s 13.16 d β341,···	30.07 a	<b>2.9 m</b> 32.2 m β-2.9,···	9.3 m β-4.21,···	1.06 m β-5.7, 6.21,···	24.9 s β- 5.20.···	1.8 s β-7.28, 6.9.···	1.78 s	1.
βω	.9, 411.5,···	80.4, 148.4, 51.2, 1.98, 7 536.1,	Ογ	β* .40,··· γ 667.7,··· β- γ 464.6···	a <sub>v</sub> (2.6 + 27),	γ 11.2, e <sup>-</sup> γ 604.7,	γ 787.2 no γ	β-? γ 818.5, 1048.1, 340.5,	γ 661.7D, 283.4 νω σ <sub>ν</sub> .25, ~0.4	e <sup>-</sup> β <sup>-</sup> 3.3,··· γ 1435.8, 462.8, 1009.8,	γ 1283.3, 627.3,…	γ 602.3,…	γ 48.5, 561.6, 1194.0,··· (n) ω	γ 359.6, 1326.5, 966.9, (n) ω	γ 195.3, 232.5, 306.6,···	β-8.46, γ 199.3, (n)
.93	E 1.196	·ω, ε β44 E +2.98 E37	E .35	$\beta^-$ , $\gamma$ 464.6, $\sigma_{\alpha}$ < .15 E +2.119 E -1.280	(31 + 3.9E2) 132.905447	$θ_γ$ 14E1, $ενω$ E -2.0587 E +1.229	σ <sub>γ</sub> ~8.7, 9E1 E .269	E 2.548	E 1.1756	191.9D, E 5.37	E 4.213	E 6.22	E 5.25	E 7.31	E 6.25	E
27 1/+ 36.4 d	Xe128	1/- Xe129 1/+ 8.89 d 26.44	Xe130 4.08	11/- Xe131 3/+	Xe132 26.89	11/- <b>Xe133</b> 3/+ 2.19 d   5.243 d IT 233.2   β <sup>-</sup> .346,	Xe134 10.44	11/- <b>Xe135</b> 3/+ 15.3 m 9.10 h IT 526.6 β <sup>-</sup> .91,	Xe136 8.87	Xe137 <sup>7/-</sup> 3.82 m β-4.1, 3.6,···	Xe138 14.1 m β8. 2.4.···	Xe139 3/- 39.7 s	Xe140 13.6 s	Xe141 <sup>5/(-)</sup>	Xe142 1.22 s 8-3.7, 4.2	0.96 s
ε γ 202.9, 172.1,		T 196.6.	x, (.4+?), (16+?)	11.9 d IT 163.9, e <sup>-</sup>		IT 233.2 β346, γ 80.99,		β ω γ 249.8. γ 786.9		γ 455.5,…	γ 258.4, 434.6, 1768.4, 2015.9,···	β-5.0, 4.5,··· γ 218.6, 296.6, 175.0,···	γ 805.6, 1413.6, 621.9,···	β- 6.2,··· γ 909.2, 118.7, 105.9,···	γ 571.9, 657.1, 538.3, 618.3,···	γ 140, 194
$\sigma_{\alpha} < 0.01$ (4	5 + ?). (E1 + ?)	γ 39.6, e <sup>-</sup> σ <sub>γ</sub> -21, -25E1		σ <sub>γ</sub> 9E1, 9E2	$\sigma_{\gamma}$ (.05 + .4), (.9 + 4)	$\hat{\sigma}_{\gamma}$ 2E2	$\sigma_{\gamma}$ (3.0 mb + .26)	σ <sub>γ</sub> 2.6E6, ~7.6E3	σ <sub>γ</sub> .26, .7	E 4.17	E 2.77	E 5.06	E 4.1	(n) ω E 6.2	(n) ω E 5.0	
26 2-	1127 5/+	128.904779 1128 1+	129.903507 1129 7/+	130.905082 2+ <b> 130</b> 5+	131.904154 1131 7/+	(8 <sup>-</sup> ) <b>1132</b> 4 <sup>+</sup>	133.905394 (19/ <sup>-</sup> ) <b>  133</b> 7/+	(8) - <b>  1134</b> (4) +	135.90722 1135 7/+	(6 <sup>-</sup> ) <b>1136</b> (1 <sup>-</sup> )	I137 (7/+)	I138 (2-)	I139 (7/+)	<b>1140</b> (3)	1141	11
.0 d	100	25.00 m	1.57E7 a β15	9.0 m IT 39.96, β-1.04, 6-62,	8.020 d β606,···	1.39 h 2.28 h IT 98, e <sup>-</sup> β-1.22,	9 s 20.8 h IT 74.0, β-1.24,		6.57 h β-1,3, 0.9,···	47 s   1.39 m $β$ <sup>-</sup> 4.3,	<b>24.5 s</b> β <sup>-</sup> γ 1218.0, 601.1,	6.5 s β-~7.4, ~6.9, γ 588.9, 875.2,	2.30 s β- γ 527.7, 571.1,···	0.86 s β- γ 376.7, 457.6,···	0.45 s β- γ 338-572 ? (n) .1655	β- ~0
ay 6	5.2, -1.50E2	y 442.9, F B er T 743.4 sp	γ 39.6, e <sup>-</sup> σ <sub>γ</sub> (20+10), 5E1	e <sup>-</sup> β <sup>-</sup> 2.5, γ 536.1, 739.5	γ 364.5,··· σ <sub>γ</sub> 0.7, 8	$\gamma \sim 22$ 2.16, $\beta = 1.47, \cdots$ $\gamma = 599.8, 667.7$ 772.6	e <sup>-</sup> γ 647.4, 912.6, γ 529.9,	γ 44.4 β- γ 847.0, 884.1,	γ 1260.4, 1131.5, 526.6D,···	γ 1313.0, 381.4, 197.3D, 7 1313.0, 1321.1,	1302.6, 1220.0,··· (n) .38, .50, .57,···	(n)	(n) .1356	(n)	(n) .1655	
	126,904458	c, 22, -10 E -2.119 E+1.252	E.194	<sup>∂</sup> γ 18 E 2.949	E .971	772.6,··· E 3.58	E 1.757	884.1,··· E 4.05	E 2.63	E 6.93	E 5.88	E 7.8 Te137(7/-)	E 6.81 Te138	E 8.9 Te139	E 7.6	Te
125 1/+	Te126 18.84	11/ Te127 3/+ 109 d 9.4 h	Te128 31.74 7.7E24 a	33.6 d 1.16 h 1T 105.5, β-1.45,	Te130 34.08 2.5E21 a	11/- Te131 3/4 1.35 d 25.0 m	3.20 d	(11/-) <b>Te133</b> (3/+) 55.4 m   12.4 m	Te134 42 m	Te135(7/-)	Te136 17.5 s β-2.5,	2.5 s	1.4 s	16100	10140	
8,	(.13 + .9),	1T 88.3 e β .69, γ 417.9, γ 57.6, 360.3 ω,	β-β-	β-1.61, γ 695.9, γ 27.8,	0.07	$\beta^{-}.42, \cdots$ $\gamma$ 7773.7, 852.2, $\beta^{-}2.1, \cdots$ $\gamma$ 149.7, 452.3,	228 3 49 7	$\beta^{-}2.4, \cdots$ $\gamma$ 912.7, 647.5, 864.0, $\gamma$ 912.1, 407.6,	β <sup>-</sup> .6, .7,···· γ 767.2, 210.5, 277.9, 79.5,	β-6.0, 5.4,··· γ 603.5, 266.8, 870.3,···	γ 2078.0, 334.0, 578.8,···	y 243.3, 554.0, 469.1, 358.6,···	(n)			
10, 10, 21	(7 + 8)		σ <sub>γ</sub> (.015+.20), (.074+~1.55) 127.904461	γ 695.9, 27.8, Ε 1.498	(.1+.34) 129.906223	IT 182.4, e <sup>-</sup> E 2.233	E .517	864.0, 407.6, IT 334.2 E 2.9	 E 1.51	E 6.0	(n) .429,··· E 5.1	(n) E 6.9	E 6.4	E 8.0	E7	E
b124 3-	125.903306 Sb125 7/+	(3) - Sb126 (8) -	Sb127 7/	5+ Sb128 8	(19/-)Sb1297/+	Sb130 (8	Sb131 (7/+	(8 <sup>-</sup> )Sb132 <sup>(4+)</sup>	Sb133 <sup>(7/+)</sup>	(7-)Sb134 (0-) 10.4 s   0.8 s	Sb135(7/+)	Sb136 1- 0.92 s	Sb137 ~ 0.9 s	Sb138	Sb139	
n 60.20 d	2,758 a 302, 13 ··· 427 9, 600.6	~11 s 12.4 d β-1.9, y 17.7D.e- y 666.4.	3.84 d β89, 1.10, γ 685.7, 473.6,	10.1 m $\beta^{-}2.6, \cdots$ $\gamma$ 754.0, 743.3, 754.0	$\beta^{-}$ $\beta^{-}$ .65, $\beta^{-}$ .65, $\gamma$ 812.6,	6.3 m $\beta^{-}2.2.\cdots$ $\gamma$ 839.5, 793.5. $\gamma$ 839.4, 793.5.	β-1.31,··· γ 943.3, 933.1,	β- γ 973.9, γ 973.9,	β-1.20,··· γ 1096.2, 2755,	$\beta^{-}6.1$ , $\beta^{-}8.4$	β <sup>-</sup> γ 1127, 1380,··· (n) 1.458, 1.042,	β <sup>-</sup> γ 606.6, 961.7	β- (n)			6.22
9 602.8 1651.6 772.8	635.9, 463.4,	γ 17.7D.e γ 666.4, (5)+ 19.0 m β 1.9 γ 414.6, 	784.0,	743.3, 314.1, IT 754.0	433.8,··· 544.5,	182.3	642.3,	696.8, 696.9,	863.9, 2416,··· E 4.00	γ 1297.4, 297.1, 706.3, 115.2 (n) ω E 8.39	1.201,···· γ 1279 E 8.1	γ 658.5,··· E 9.8	E 9.3	E 11	E 10.	
458 E 2,904	E .767	666.4, E 3.67 3/+ Sn125 11/-	E 1.58	E 4.38	γ 1128.4 E 2.38	E 4.96	E 3.2 +) (7 <sup>-</sup> ) <b>Sn130</b>	E 5.49	Sn132	Sn133(7/-)	Sn134	Sn135	Sn136	Sn137 0.24 s	88	6.41
n123 11/ m 129.2 d	Sn124 5.79	9.5 m 9.64 d	2.3E5 a β25	4.15 m 2.12 h β-2.72, β-3.2, 2.42,	6.5 s 59.1 m	6.9 m $\beta^-2.9, \cdots$ $\gamma$ 1161.4, 1128.5,	17 m   372 m	58.4 s β-3.4, γ 1226.0, β-3.8,	39.7 s β-1.76 γ 85.6, 340.5,	1.44 s β-7.5, 6.9,···	1.04 s β- γ 872, 317, 554,···	0.53 s β- γ 281.7, 732.4,	0.26 s β- (n)	β- (n)	6.77	
3, 7 1088.6, 	z <sub>y</sub> (.13 + .004),	γ 331.9,··· γ 1067.0, 1089.2, 822.4.	γ 87.6,	γ 491.2, γ 1114. 1095	3, 7 831.5, 75.1,···	1128.5,	γ 144.9, 779.8, 69.7,	450.0, 798.5, ···	246.9, 890.0, 992.7,···	γ 962.2,··· (n) ω	(n) .32 –1.02	923.4 (n) γ 317.8 E 8.9		F.40		
28 E 1.403	(8+7) 123.905275	915.5,·· E 2.387 E 2.363	E .38	E 3.21 E 3.20		E 4.0	E 2.15	E 4.69	E 3.11 (21/+) <b>In131</b> (9/+)	E 7.99	E7.4	In134	In135	E 10.	0.40	
In122 1+ 1	1/- In123 9/	+ (8 <sup>-</sup> ) In124 34 3.4 s   3.18 s $\beta^{-}$ 5,	1/(¬) <b>In125</b> 9/( 12.2 s 2.36 s β-5.51, β-4.08,	163 e   153	s 3.73 s 1.14 s	0.7 s   0.80 s	(1/-) In129(9/- 1.23 s 0.63 s $\beta$ -7.5, $\beta$ -7.5,	0.53 s 0.29 s β-8.8, β-6.1,	0.3 s   0.28 s	0.20 s	165 ms	0.14 s	0.09 s β- (n)	6.32	6.19	
3 s 1.5 s β 5.3, γ 1140.3, γ	47 s β-4.6 γ 125.8. γ 1019 γ 1019	1 1131 6 v 1131.6	$\beta^{-}5.51$ , $\beta^{-}4.08$ , $\gamma$ 1335.	$\beta$ 4.45, $\beta$ 4.86, $\gamma$ 1141.1, $\gamma$ 1141.1, $\gamma$ 1141.3	$\beta^{-}6.4, \cdots$ $\gamma^{-}252.3, \cdots$ $\gamma^{-}1.1,  (n) \omega$ $\beta^{-}4.9, \cdots$ $\gamma^{-}1597.7$	1866.9.	8, 7 315.3, 7 2118. 8, 1865.	1, y 1221.2. y 1905.2	$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	γ 375, 4041, 299,··· (n)	γ 1561 ω (n)	(n) γ 1561	(11)	0.52		
0. s		969.9, 1072.9, 102.9,  E 7.36	E 5.42	908.6, 111.8,  E 8.2		1973.7, (n) ω E 8.98	(n) ω	β 6.1, (n) ω γ 2258.8, Ε 10.25	γ 332, 1655 E 9.17	E 14.1	E 13.5	E 15				
Cd121(3/+)	E 4.39 Cd122	(11/-)Cd123(3/)	+ Cd124	(11/-) Cd125(3	(+) Cd126	Cd127(3/ 0.4 s	+) Cd128 0.28 s	Cd129 0.27 s	Cd130 0.16 s	Cd131 68 ms	Cd132 0.01 s	0.70	7.87	6.54		
s 13.5 s	5.3 s β- γ 854, 1013,	1.84 s β- γ 1165.9, γ 371.3 1027.5, 1052.	R-	$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	B-	β- γ 1235.1, 376.3, 523.6, 1067,	$\frac{\beta^{-}}{\gamma}$ 247.9, 857.0	γ 281	β γ 1395 (n)	(n)	(n)	6.70	7.07	0.0		
059.6. 7 324.3. 1020.9. 1040.4. 349.3.	1275,	1027.5, 1052. IT?		2147	7,	E 8.5	E 7.1	E 9.9	E 8.5						_	
E 4.8	E 3.0	(+) Ag122 (3)	+) Ag123(7	(+) Aq124	Ag125	Ag126	Ag127	Ag128	Ag129		84					
Ag120 3(+)	Ag121(7 0.78 s	0.55 F	0.30 8	0.17 s	0.17 s β-	0.10 s	79 ms	0.06 s β- γ 645, 784	0.05 s β- (n)	1.81	2.89	4.31				
505.9, $\gamma$ 505.9, 697.8,	γ 314.7, 353.6,·· (n) ω	733.1	γ 263.9, 409.8,··· (n) ω	γ 613 (n) ω		γ 652, 815, 827, 857										
203 E 8.3	E 6.4	(n) ω E 9.1	E 7.4	E 10.1	E 8.7	E 11.3	E 10.	1	82							
Pd119 0.9 s	Pd120	Pd121	Pd122	Pd123	Pd124		80	0.157	0.35	0.54						
129.9, 256.6, 326.1,···	β <sup>-</sup> γ 158.1, 89.9,···					0.034	0.059	0.137	0.55	0.54						
E 6.5	E 4.9	E8	E 6	E 9		4										
Rh118	Rh119	Rh120	Rh121	Rh122	1.0											
0.3 s γ 379.0, 574.6					0.0157	0.027										
		- F.	E 9													
E 10.	E8	E 11	-				The state of the s	13410 - 1148								

#### SO, WHERE ARE WE...

- \* 500 yds horizontal distance low exposure from burst 10m underground
- Low exposure from surface (assuming overburden)
- \* Assume widespread contamination at surface radiation
- \* Assume widespread devastation at surface
- \*? contaminated air infiltration
- \* Hopefully someone knows where we are (were)
  - Kinda busy with other issues
  - \* Time is available for us to survive

#### NCRP 161 TABLE

Factors like mouth breathing, respiratory issues, etc., actual particle size, and chemical composition complicate calculations.

Deterministic effect is an observable effect, not a risk-based (somatic) effect like cancer, and doesn't need to be fatal.

Time scale for given effect is 2-3 months post-exposure.

TABLE 3.12—Estimates of the concentrations in air [MBq  $m^{-3}$  ( $\mu$ Ci  $m^{-3}$ )] of several radionuclides that would have to be inhaled for 10 min to achieve intakes sufficient to produce deterministic effects or give effective doses of 0.25 Sv (25 rem) (Section 16.7).

Radionuclide <sup>a</sup>	Air Concentrations Required to Cause Deterministic Effects <sup>b,c</sup>	Air Concentrations Required to Result in an Intake of 1 CDG Leading to an Effective Dose of 0.25 Sv (25 rem) <sup>c</sup>			
$^{90}\mathrm{SrCl}_2$ (Type F)	2,600 (70,000) Bone-marrow depression	51	(1,400)		
<sup>131</sup> I (Vapor)	30 (800) Hypothyroidism	76	(2,100)		
<sup>137</sup> CsCl (Type F)	8,000 (220,000) Bone-marrow depression	350	(9,500)		
$^{144}\mathrm{CeO}_2$ (Type S)	3,700 (100,000) Pneumonitis	52	(1,400)		
$^{210}\mathrm{PoCl}_2$ or $^{210}\mathrm{PoCl}_4$ (Type M)	1,900 (51,000) Bone-marrow depression	0.67	(18)		
<sup>238</sup> PuO <sub>2</sub> (Type M)	40 (1,100) Pneumonitis	0.049	(1.3)		
$^{239}$ Pu $O_2$ (Type S)	40 (1,100) Pneumonitis	0.18	(4.9)		
$^{241}\mathrm{AmO}_2$ (Type M)	40 (1,100) Pneumonitis	0.57	(1.5)		

 $<sup>^</sup>a The\ radionuclides\ shown\ here\ are\ used\ as\ examples\ to\ demonstrate\ the\ levels\ of\ airborne\ activity\ required\ to\ cause\ serious\ health\ concerns.$  Assumed a breathing rate of 1.2 m³  $h^{-1}$  of unfiltered air for an adult and a lognormal particle-size distribution with AMAD = 5  $\mu m$ .

<sup>&</sup>lt;sup>b</sup>Deterministic effects expressed within two to three months are given for the particular radionuclide.

<sup>&</sup>lt;sup>c</sup>Calculations based on a breathing rate of 1.2 m<sup>3</sup> h<sup>-1</sup> of unfiltered air by an adult,  $5 \mu m$  AMAD particles, and a total deposition of 82 % (ICRP, 1994a).

#### ALL IS NOT LOST!

The plans for Operation Teapot, at the Nevada Proving grounds during 1955, included a series of Civil Effects Tests, one of which, Project 32.2, covered the exposure of packaged food products. As this project developed, it was expanded to cover representative commercially packaged beverages, such as soft drinks and beer, in glass bottles and metal cans.

Preliminary experimental results were obtained from lest layouts exposed to a detonation of approximately nominal yield. Extensive test layouts were subsequently exposed during Operation Cue, of 50 per cent greater than nominal yield, at varying distances from Ground Zero. These commercially packaged soft drinks and beer in glass bottles or metal cans survived the blast overpressures even as close as 1270 ft from Ground Zero, and at more remote distances, with most failures being caused by flying missiles, crushing by surrounding structures, or dislodgment from shelves.

Induced radioactivity, subsequently measured on representative samples, was not great in either sort drinks or beer, even at the forward positions, and these beverages could be used as potable water sources for immediate emergency purposes as soon as the storage area is safe to enter alter a nuclear explosion.

Although containers showed some induced radioactivity, none of this activity was transferred to the contents. Some flavor change was found in the beverages by taste panels, more in beer than in soft drinks, but was insufficient to detract from their potential usage as emergency supplies of potable water.

Half life was observed to be 12-15 hours – Na 24 is 15 hours

#### RADIATION DAMAGE

- \* Ionizing radiation ionizes materials
- Free radicals produced
  - Oxygen and water easily involved in free radical formation
    - Form peroxides
  - \* Free radical scavengers are radioprotective
    - \* Must be there at time of formation
  - May inactivate cellular mechanisms, interact with DNA or RNA directly
    - Cells most sensitive during mitosis

#### RADIOSENSITIVITY OF NORMAL CELLS

- Very high: Lymphocytes, Immature hematopoietic cells, Intestinal epithelium,
   Spermatogonia, Ovarian follicular cells
- \* **High:** Urinary bladder epithelium, Esophageal epithelium, Gastric mucosa, Mucous membranes, Epidermal epithelium, Epithelium of optic lens
- Intermediate: Endothelium, Growing bone and cartilage, Fibroblasts, Glial cells, Glandular epithelium of breast, Pulmonary epithelium, Renal epithelium, Hepatic epithelium, Pancreatic epithelium, Thyroid epithelium, Adrenal epithelium
- \* Low: Mature hematopoietic cells, Muscle cells, Mature connective tissues, Mature bone and cartilage, Ganglion cells

# HIGH RADIATION EXPOSURE

Shielding 10% of active bone marrow may result in no deaths in LD50 range

Susceptibility varies with age, concurrent medical issues

With appropriate supportive therapy individuals may survive whole body exposures > 1200 R

In animals LD50 values are ~20% higher for unilateral vs bilateral exposure, and dorsal is about 2/3 of the ventral value

For children values are probably factor of 2 lower.

Highest value probably about puberty, and decreases with age

From Medical Effects of Ionizing Radiation, Mettler, F. A. and Moseley, R. D., Eds., Grune & Straiton, New York, 1985

#### Expected Temporal Distribution of Symptoms Following Whole-Body Irradiation

Midline tissue dose	Symptom	Percentage	Time postexposure	
0.5—1.0 Gy (50—100 rads)	Anorexia	15—50	3—18 h	
	Nausea	5—30	3-20 h	
	Vomiting	15-20	4—16 h	
1-2 Gy (100-200 rads)	Anorexia	50-90	1-48 h	
	Nausea	30—70	4-30 h	
× .	Vomiting	20-50	6—24 h	
	Fatigue	25—60	3—72 h <sup>a</sup>	
	Weakness	25—50	3—48 h	
	Bleeding (mild)	10	1-5 weeks	
	Fever	10—60	2 d—5 weeks	
	Infection	10-50	1-5 week	
	Death	<5	5—6 week	
2—3.5 Gy (200—350 rads)	Anorexia	90—100	1—48 h	
	Nausea	70—90	1—48 h	
	Vomiting	50—80	3—24 h	
	Diarrhea	10	4—8 h	
	Fatigue (moderate)	60—90	2 h—6 weeks	
	Weakness (moderate)	50—80	2 h—6 weeks	
	Bleeding	10—50	1—5 week	
	Fever	10—80	1—5 week	
	Infection	10—80	2—5 week	
	Ulceration	30	3—5 week	
2.5 5.5 0 (250 550 1)	Death	5—50	4—6 week	
3.5—5.5 Gy (350—550 rads)	Anorexiab	100	1—72 h	
	Nausea <sup>b</sup>	90—100	1—72 h	
	Vomiting <sup>b</sup>	80—100	3—24 h	
	Diarrhea <sup>b</sup>	10	3—8 h	
	Fatigue	90—100	1 h—6 weeks	
	Weakness	90—100	1 h—6 weeks	
	Headache	50	4—24 h	
	Bleeding Fever and infection	50—100	6 d—6 weeks	
	Death	80—100	6 d—6 weeks	
5.5—7.5 Gy (550—750 rads)	Anorexia	50—99	3.5—6 weeks	
3.5—7.5 dy (350—750 lads)	Nausea	100 100	1—72 h	
	Vomiting	100	1—72 h	
	Diarrhea		1—48 h	
	Fatigue and weakness (severe)	10	4—6 h	
	Dizziness and disorientation	100	1 h—2 weeks	
	Headache	100 80	4—48 h	
	Bleeding, fever, infection, hy-	100	4—30 h	
	potension	100	10—14 d	
	Death	100	2—3 weeks	
		100	2—3 weeks	

Possibly up to 6 wk.

Symptom occurs in 60—100% of those exposed at 3—6 weeks.

## FOUR PHASES OF ACUTE RADIATION SYNDROME #1 - PRODROMAL

- - Transitory symptoms, proportional to dose
  - Abnormalities in autonomic nervous system responsible for early GI symptoms
    - Anorexia, nausea, vomiting, diarrhea, intestinal cramps, salivation, and dehydration
  - Can be prevented by shielding the abdomen, unless large doses to the head
- \* 200-400 R (2-4 Sv) N/V often in 1<sup>st</sup> two hours, mild headache, no diarrhea, temp increases in 10-80% in 1-3 hours
- \* 400-800 (4-8 Sv) R Vomiting is constant in < 1 hour, severe headache, diarrhea in 10 % in 1-8 hours. Fever is moderate to high in ~ 1 hr. Xerostomia & parotiditis frequent.
- >800 R (8 Sv) Vomiting in minutes, LOC may be affected, Diarrhea in minutes to 1 hour, temp up to 41 C

# FOUR PHASES OF ACUTE RADIATION SYNDROME #2 - LATENT

- Extends to 20-30 days
  - \* Reflects time from rad-induced initial cell lesions and clinical expression
    - Dependent on cell turnover
  - Days 20-30 correspond to nadir of leukocyte and platelet counts
  - < 400 R (4Sv), prodromal symptoms subside in 48 hours, and Pt is asymptomatic for 1-3 weeks, then hematologic abnormalities become obvious.
    </p>
  - 600-800 R (6-8 Sv), latent period is <7 day (then sepsis and GI)</li>
  - → > 1500 R (15 Sv) hours to vascular issues
- \* Hematopoetic growth factors can be administered
  - \* G-CSF granulocyte colony-stimulating factor used in oncology use ASAP post exposure. Not a single dose administration.
  - \* GM-CSF granulocyte macrophage-colony-stimulating factor more adverse effects, mainly capillary leakage
- \* Stem Cells (?)

The Medical Basis for Radiation-Accident Preparedness, R.Ricks, et.al. Eds. New York,

# FOUR PHASES OF ACUTE RADIATION SYNDROME # 3 - MANIFEST ILLNESS

#### \* Hematopoietic

- → >200 R (2 Sv), up to 700 R (7 Sv)
- Damage to bone marrow stem cells and lymphatic organs
- \* Rapid reduction in lymphocytes (w/I 48 hours), may be transient rise in granulocytes and platelets, but then a decrease, with nadir in ~30 days

#### \* Gastrointestinal

When trunk exposure >700 R (7 Sv), latent period 1-4 days. <1200 R (12 Sv) regeneration of bowel epithelium is possible. Otherwise loss of mucosal crypt cells. Mortal in 3-14 days,</p>

#### \* Cardiovascular

- \* Debates about cardiovascular or neurovascular syndrome
- Central Nervous System
  - \* Initial nerve stimulation, then cerebral edema ~ 10 kR (100 Sv)
  - Mortality in 36-48 hours

# FOUR PHASES OF ACUTE RADIATION SYNDROME # 4 - RECOVERY... OR NOT

- Mucosal lesions on tonsils, pharynx, nasal passages, and tongue.
- Edema may extend to larynx.
- 500-1000 R (5-10 Sv) hyperemia of oral and nasal cavities. Day 4-5 edema of soft palate and posterior pharynx. Followed by bleeding, ulceration, and necrosis. Healing is slow, but improved with antibiotics.
- Oropharyngeal changes seen in Chernobyl Pts, in days 8-25 desquamation and edema of tongue and cheeks, gum tenderness.
- Pulmonary changes can occur Chernobyl respiratory insufficiency and pneumonitis, autopsies revealed interstitial edema (14-30 days to death), but no destruction of tracheal or bronchial epithelium.

## RADIONUCLIDE CONTAMINATION

- Chelating (from chele Latin/Greek for claw)
  - Binds to metal ions, sequesters, and is excreted

  - In-DTPA is less toxic, and is as effective as Ca-DTPA for long-term
  - Plutonium, americium, curium, and californium. Debates about Np, Th, and U
- \* Blocking -lodine
- \* Isotopic dilution Tritium
- \* Alter its chemistry NaHCO3 for uranium carbonates in renal tubules
- Binding Prussian blue for cesium and thallium
- \* Procedures Emesis, gastric lavage, cathartics, bronchoalyéolar lavage

#### WORKING A RAD CASUALTY

- \* Contamination
  - Their contamination is unlikely to affect caregiver
    - It's been a while from exposure to treatment
    - Your exposure time will probably be short in comparison to theirs
    - Otherwise it may not be advised triage
- \* Fragment
  - Caregiver shielding
- **\*IT DEPENDS**
- \* 10 R (100 mSv)/hr source in the palm
- \* Heavy contamination/moderate/deconned?

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